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THE VIABILITY OF USING SLIPFORM CONCRETE CONSTRUCTION  
TECHNIQUE AS AN ALTERNATIVE TO CONVENTIONAL  
FORMWORK IN THE NAVAL CONSTRUCTION FORCES

BY

MARK EUGENE BANKS

A REPORT PRESENTED TO THE GRADUATE COMMITTEE  
OF THE DEPARTMENT OF CIVIL ENGINEERING IN  
PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

SPRING 1986



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## ABSTRACT

Portland Cement Concrete has been used in the construction industry for approximately 120 years to provide a strong, durable and relatively long life structure. The desire to replace the non-reuseable plywood forms in vertical construction and the heavy steel forms used in the construction of pavements has prompted many individuals to seek alternative methods. Slipform construction is an alternative which has been very successful in the private sector and the idea of employing this rapid construction technique in the U. S. Navy is investigated in pages that follow. The report begins with a cursory review of basic concrete design principles to establish a starting point. An indepth look at the vertical slipform technique is presented with particular attention being taken to accentuate the requirement for highly skilled labor to make the system work efficiently. A discussion of the conventional method of paving concrete roads is presented followed by an address concerning the horizontal slipform technique. The Department of the Navy and the Naval Construction Forces are introduced to provide the necessary insight needed to make a decision on whether the slipform technique can be used in the Navy. The manpower availability, training programs and objectives of the Navy are discussed to provided the information needed in order to reach a conclusion.



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## Chapter 1

### Introduction

Portland Cement concrete has been used in the construction industry for approximately 120 years. The competitiveness of the industry has prompted individuals to search for better construction techniques in the implementation of this material. There is much debate over which concrete forming method is the most efficient and cost-effective. The debate moves into an entirely different arena however, when concrete construction is attempted in a hostile or remote environment by military personnel. The U. S. Navy has been assigned the mission of providing construction support to amphibious forces in combat areas as well as the construction of any support facilities that may be required. This mission is carried out by the Naval Construction Forces, which is quite capable of utilizing whatever resources are available to fulfill the task.

The question to be addressed in this paper is whether the technique of slipform concrete construction, which is very well received in the private sector, is a viable alternative to the conventional formwork technique employed in the Naval Construction Forces. This report will provide a cursory review of concrete construction



practices. The report will discuss in detail the techniques of vertical and horizontal slipform construction and provide advantages and disadvantages for each technique. The paper will then provide a brief introduction into the Department of the Navy, a synopsis of the Naval Construction Force's history, a presentation of the training and responsibility of Naval Enlisted personnel, and the current methods being employed to construct concrete structures by the Naval Construction Force.



## CHAPTER II

### REVIEW OF CONCRETE CONSTRUCTION PRINCIPLES

#### Portland Cement Concrete

The use of some form of cement to bind together stones, gravel and other material has been practiced from very early times. The Egyptians certainly used lime mortar in the construction of their pyramids. One of the most notable examples of Roman work which still remains is the Pantheon, the dome of which is 142 feet 6 inches in span and cast in solid concrete. Joseph Aspdin ,one of the first to use the term Portland cement, in 1824 described a patent cement formed by heating a mixture of finely divided clay and limestone or chalk in a furnace to a temperature sufficiently high to drive off all the carbon dioxide.(1-1) It was called Portland cement because the appearance of the resulting concrete resembled Portland stone. It was not until 1845 at Swanscombe that Isaac C. Johnson invented the cement which was the prototype of our modern cement, by increasing the temperature at which the limestone and clay were burned until they formed a clinker.(1-1) From then onward many refinements and technical changes produced a gradual improvement in the quality of cement.

Improvements in Portland cement production and in the



technique of concrete construction have greatly accelerated in recent years. Concrete is a building and structural material the properties of which may be predetermined by careful design and control of the constituent materials. These constituent materials are, a hardening binding medium or matrix formed by a chemical reaction between cement and water and the aggregate to which the hardened cement adheres to a greater or less degree. The aggregate may be gravel, crushed rock, slag, artificial lightweight aggregate, sand or other similar material. The aggregate, the cement and the water are all mixed together and in this state are plastic and workable, properties which permit moulding into any desired shape. Within a few hours of the preparation of the mixture, the cement and water undergo a chemical reaction, hydration, which results in hardening and the development of strength.

#### Concrete Limitations

The limitations and disadvantages of concrete construction must be realized and provisions taken to correct potential deficiencies of concrete structures. The elimination of costly difficulties in concrete construction procedures, cracking, and other structural weaknesses that detract from the appearance, serviceability, and life of the structure must be factored into the design of the concrete structure. (1-2) The principal limitations and disadvantages are:



1) Low tensile strength. Members which are subjected to tensile stress must, therefore be reinforced with steel bars or mesh.

2) Thermal movements. During setting and hardening the temperature of the concrete is raised by the heat of hydration of the cement and then gradually cools. These temperature changes can cause severe thermal strains and early cracking. Hardened concrete expands and contracts with changes in temperature at roughly the same rate as steel. Expansion and contraction joints must be provided in many types of structures if failures are to be prevented.

3) Drying shrinkage and moisture movements also pose problems. Concrete shrinks as it dries out and even when hardened expands and contracts with wetting and drying. These movements necessitate the provision of contraction joints at specified intervals if unsightly cracks are to be avoided.

4) Creep. Concrete gradually deforms under load, the deformation due to creep not being totally recoverable when the load is removed.

5) Permeability. Even the best concrete is not entirely impervious to moisture and contains soluble compounds which may be leached out to a varying extent by



water. Joints, unless special attention is given to their construction, are apt to form channels for the ingress of water. Impermeability is particularly important in reinforced concrete where reliance is placed on the concrete cover to prevent rusting of the steel. (1-4)

#### Elementary Principles of Reinforced Concrete Design

The necessity for the use of concrete and steel together arise from the nature of the stresses which result from loading. These are compressive, tensile, and shear stresses, which may occur in different members singly or all together. Dense concrete has sufficient compressive strength, but its tensile strength is extremely low. (1-272) Tests have shown that the tensile strength is, in fact, only about one-tenth of its compressive strength. (1-272) Steel on the other hand, has a high tensile strength as well as a high compressive strength when adequate lateral support is provided to prevent bucking. Suitable combinations of these two materials provide resistance to both compressive and tensile forces. Fundamentally, the combination of concrete with steel reinforcement is made possible by two fortunate physical properties. First, the coefficient of thermal expansion of concrete is almost identical to that of steel and secondly, unless impurities are present, concrete is alkaline, providing an environment which inhibits the rusting of the



reinforcement. (1-272) A further requirement for the efficient use of steel reinforcement in concrete is that the concrete grips, or bonds well with the steel. (1-277) Shear is comprised of two components acting simultaneously; horizontal shear due to changes in length and vertical shear producing a vertical slicing or guillotine action.

Beams, columns and slabs comprise the three basic elements of most structures. The behavior of slabs under load, in respect to end conditions and over intermediate supports, is similar to that of beams. (1-282) It may be shown that for any point along the beam the value of the horizontal shear is equal to that of the vertical shear, the resultant acting at 45 degrees to the beam or slab axis. Normally, the effects of shear are most severe at the ends of a beam/slab and on either side of an intermediate support. The shear force at any point along a beam gives rise to pure tensile and compressive forces in the concrete, again inclined at 45 degrees to the axis of the beam, at the neutral axis level. The concrete is normally capable of resisting the compression set up by the shear forces, but has very little ability to resist the corresponding tensile forces. Consequently, under certain conditions of loading shear cracks may occur on the lower half of the beam near the supports. These cracks will be perpendicular to the tensile plane. Shear reinforcement



must then be provided in addition to, and to act with, the longitudinal reinforcement. This shear reinforcement may be in the form of bent up bars or vertical stirrups. In practice a slab designed to span one way only, will try to some degree to span in the other direction due to the monolithic nature of the construction.(1-282) Slabs may be reinforced using a prewelded fabric mesh of small diameter wires, usually supplied as standard sheets or rolls, or by using rod reinforcement.

### Bond and Anchorage

An effective bond between the concrete and the reinforcement is essential since the efficient use of the combination of steel and concrete is dependent upon the transfer of stresses from the concrete to the steel.(1-283) The bond strength or the measure of the effectiveness of the grip between the concrete and the steel is best defined as the stress at which a very small slip occurs.(1-283) Bond is due initially to adhesion and frictional resistance, but as soon as slipping begins the adhesion fails and the subsequent bond is due to friction and mechanical resistance. The bond strength is improved by increasing the crushing strength of the concrete but is not directly related to it.(1-283) The development of bond strength is most rapid under moist curing conditions. Deformed bars, bars with a pattern of raised ribs or square



twisted, permit higher bond stresses than plain round bars. The accepted ratio for practical design purposes in the bond strength of plain bars, twisted bars and ribbed bars is 1:1.4:1.8. Bars which are stressed must extend for a sufficient distance from any stressed section to develop a satisfactory resistance to failure of the bond between the bar and the concrete. (1-283)

In general hooks and bends are used at the ends of bars to reduce the length of straight that would otherwise be required for anchorage. Standard hooks for mild steel bars should have an inner diameter of at least four times the diameter of the bar, where if high yield steel is being used the inner should be at least six times the diameter of the bar. (1-284) For both types of steel, the length of the straight portion of the bar beyond the end of the curve to the end of the hook should be at least four times the diameter of the bar. Loose or flaking rust, paint or oil on a reinforcing bar is detrimental to the bond and must be removed before fabrication of the reinforcement. (1-285) Cement grout on a bar is also acceptable provided it firmly adheres to the bar.

### Concrete Formwork

Forms are essential to concrete construction. They control position, alignment, size, and shape of the structure. Formwork also serves as a temporary support



structure for materials, equipment, and workers. The objectives of a form builder should be threefold:

1) Quality- to design and build forms accurately so that the desired size, shape, position and finish of the cast concrete are attained.

2) Safety- to build substantially so that the formwork is capable of supporting all dead and live loads without collapse or danger to workmen and to the concrete structure.

3) Economy- to efficiently, saving time and money for the contractor and owner alike. (2-17)

Economy is a major concern because formwork costs may range anywhere from 35 to 60 per cent of the cost of the concrete structure.

#### How Formwork Affects Concrete Quality

Size, shape and alignment of slabs, beams and other concrete structural elements depend on accurate construction of the forms. The forms must be 1) of correct dimensions, 2) sufficiently rigid under construction loads to maintain the designed shape of the concrete, 3) stable and strong enough to maintain large members in alignment, and 4) constructed so that they can withstand handling and reuse without affecting their dimensions. (2-18) Formwork must remain in place until the concrete is strong enough to carry its own weight, or the finished structure may be damaged. The quality of surface finish of concrete is affected by the form material used. The correct combination of form material and oil or other parting compound can contribute to eliminating air holes or other



surface imperfections in the cast concrete. (2-18)

#### Formwork Safety- Causes of Failure

Premature stripping of forms, premature removal of shores and careless practices in reshoring have caused numerous failures or deficiencies in completed concrete structures. (2-19) Improper stripping and reshoring may cause sagging of partially cured concrete and development of fine hairline cracks, which may later create a serious maintenance problem. Inadequate size and spacing of reshores may lead to a formwork collapse during construction as well as to damage of the concrete structure. Inadequate cross bracing and horizontal bracing of shores is one of the factors most frequently involved in formwork accidents. Investigations of cases involving thousands of dollars of damage show that the damage could have been prevented or held to a lesser amount if a few hundred dollars had been spent on diagonal bracing for the formwork supports. (2-19) Temperature and rate of vertical placement of concrete are factors influencing the development of lateral pressures that act on the forms. If temperature drops during construction, rate of concrete placement must be decreased to prevent a buildup of lateral pressure from overloading the forms. Failure to properly regulate the placement of concrete on horizontal surfaces or arched roofs may produce unbalanced loadings and



consequent failures of formwork. Table No. 1 provides a compilation of research data gather to assist formwork designers in the calculation of lateral wall pressures.



TABLE NO. 1\*

MAXIMUM LATERAL PRESSURE FOR DESIGN OF WALL FORMS

Based on ACI Committee 622 pressure formula

*Note.* Do not use design pressures in excess of 2000 psf or  $150 \times$  height of fresh concrete in forms, whichever is less.

Rate of placement, <i>R</i> (ft per hr)	<i>p</i> , Maximum Lateral Pressure, psf, for Temperature Indicated					
	90° F	80° F	70° F	60° F	50° F	40° F
1	250	262	278	300	330	375
2	350	375	407	450	510	600
3	450	488	536	600	690	825
4	550	600	664	750	870	1050
5	650	712	793	900	1050	1275
6	750	825	921	1050	1230	1500
7	850	938	1050	1200	1410	1725
8	881	973	1090	1246	1466	1795
9	912	1008	1130	1293	1522	1865
10	943	1043	1170	1340	1578	1935

\* Basic Concrete Construction Practices, Portland Concrete Association, John Wiley and Sons, Inc., New York, 1975 pg 17.



## Chapter III

### Vertical Slipform Construction

#### Introduction

For approximately 100 years, vertical slipform systems have been closely associated with storage bins and silos. In this small sector of the construction arena the system has become an invaluable tool of construction, cutting cost and construction time, and at the same time compiling an impressive safety record. As time passed, assisted by technology and the competitiveness of the construction industry, slipforms have been successfully applied to many other types of structures. On any given day one can find bridge piers, apartment houses, water tanks, dam structures, and nuclear reactors shield walls being formed using the slipform system. (3-1131)

The system consists basically of lifting a form, which is kept continuously filled with concrete, at a predetermined rate so as to leave behind the permanent structure. The slipform system is often liken to an extrusion process where the forms are stationary and the material filling the forms are moved. It must be stated at the outset, the structural design of the structure must be formulated with the knowledge that a slipform system will



be used to form the structure. This will enable the structural engineer eliminate some designs immediately from consideration and seek assistance if necessary.

### Description of Slip-form Components

#### Yokes

The yokes, to which the forms are attached, are two vertical legs connected together by transom to which the screw-jack is attached. Yokes may be wood or steel and must be stiff enough to resist the lateral pressure of the concrete. The yokes should be designed so that the legs and transom are an integral self-contained rigid unit and that the transom is interchangeable to facilitate variations in the thickness of the wall. The overall height of the yoke ranges from 4 to 8 feet. The yokes must transfer the full load of the forms, finishers' scaffolding, and working deck to the jacks. Sufficient clearances above the forms to allow the horizontal reinforcement to be installed must be taken into consideration when designing the yokes. (4-2)

#### Wales

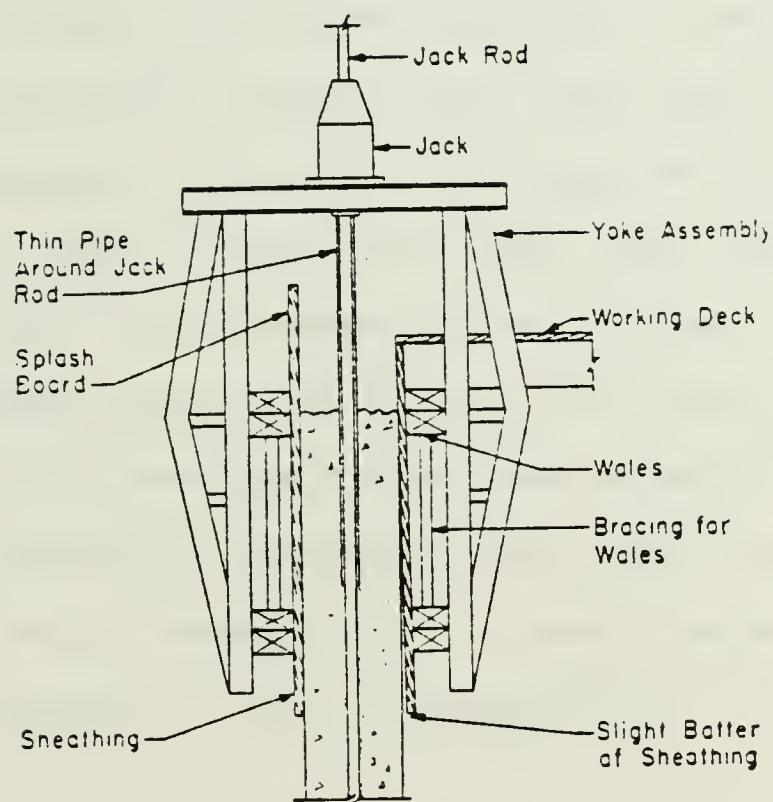
The wales connect the yokes on one sheath together while providing lateral support to the sheathing between jokes. Wales can be made of wood or steel, depending on the material of the yokes, and must be stiff enough in the



vertical direction to transfer the weight of the forms and the friction force to the yoke without excessive deflection. Walings are framed up internally to form a rigid unit to ensure the correct profile of the structure is maintained. When the span between yokes exceeds 8 to 12 feet the wales should be braced in the vertical plane between the yokes. (4-2) For illustration of Yokes, Wales, and Sheathing see figure 3-1.



Figure 3-1



\* Camellerie, J. F., Slipform Details and Techniques,  
Journal of the American Concrete Institute, 1959, p 1135.



### Sheathing

The sheathing material fixed to the walings can be made of wood or steel. In the case of steel, the forms are denser, are more difficult to assemble and repair, and have a lower thermal insulating value. They are not as flexible and tend to trap water on top of the walls. The main advantages to the steel sheathing are they have a lower frictional resistance, are easier to clean and are more durable. In the case of wood sheathing, the timber should be free from knots. Wood sheathing is difficult to clean down without damage and the frictional resistance is higher. The main advantages to the wood sheathing are they lighter, more flexible, easier to repair, and easier to dismantle part of the sheathing at a controlled stop in order to gain access to jack-rod shoes. (5-2)

The external faces of a sheathing are kept truly plumb but the internal faces should be tapered approximately 1/4 in. in their height, an 1/8 in. inwards at the top and 1/8 in. at the bottom, the true thickness of the wall being set at the mid-height of the sheathing. The sheathing on the opposite side from which the concrete is placed should be 6 in. taller or a splayed concrete splash board will aid the placing of concrete. Sheathing joints should be vertical to facilitate upwards movement without a transverse drag component. (5-3)



### Jacks - Jacking Rods

Jacks are the source of motion in the slip-form system and must be scrutinized to insure the correct system is employed. Jacks can be manual, electric, or hydraulical operated. The designer's main concern, apart from cost, is the load-carrying capacity of each jack. The load-carrying capacity of jacks can vary from 3 to 25 tons and the size of the jack-rods can range from 1 to 3 inches. The jack consists of a tubular screw that is attached to the yoke. The jack should be readily accessible for maintenance and the lowest transom should be high enough to enable the reinforcement and boxes to be installed at the predetermined rate. The jack-rod runs through a hole in the center of the screw and is held by a set of jaws on the screw. Due to the size of the cross-section of the wall, the size of the jack-rod may control the type of system to be used because the wall surrounding the jack-rod has to be strong enough to provide lateral stability to the jack-rod. (6-29)

The jack-rods or tubes carry the entire vertical loading from the sliding operation. They must be kept clean at all times to ensure that the jaws of the jack can obtain an effective grip. The connectors between each rod



need to be self-aligning so that no lips occur at the joint which will cause damage to the jaws or cause the rod to jam as it passes through the collars on the yoke transom. The jack-rod act as slender columns under load which means the designer must brace the rods as they pass through openings such as doorways. To ensure that the concrete does not bond to the rods and reduce the quantity number of rods needed on a particular project, trailer tubes are fixed to the lower transom. As the end of the tube reaches the level of the soffit of the sheathing, a cavity is formed around the rod which enables the rod to be withdrawn later.

#### Scaffolding - Working Decks

Vertical slipform system are normally composed of three layers of working platforms. The upper deck is where the operation and control of the jacks take place. Installation of the jack rods and landing, sorting, and placement of the vertical reinforcement steel, also takes place on this level. Finally, landing and distribution of the horizontal reinforcement steel, distribution of the concrete to hoppers or directly into the form, and storage of utility items is accomplished on the upper deck. The working deck is the center layer of the system and is where the distribution, placement, and consolidation of the concrete takes place. Also accomplished on the work deck is the placement of horizontal reinforcement steel, vertical steel splices, and placement of keyway and dowel

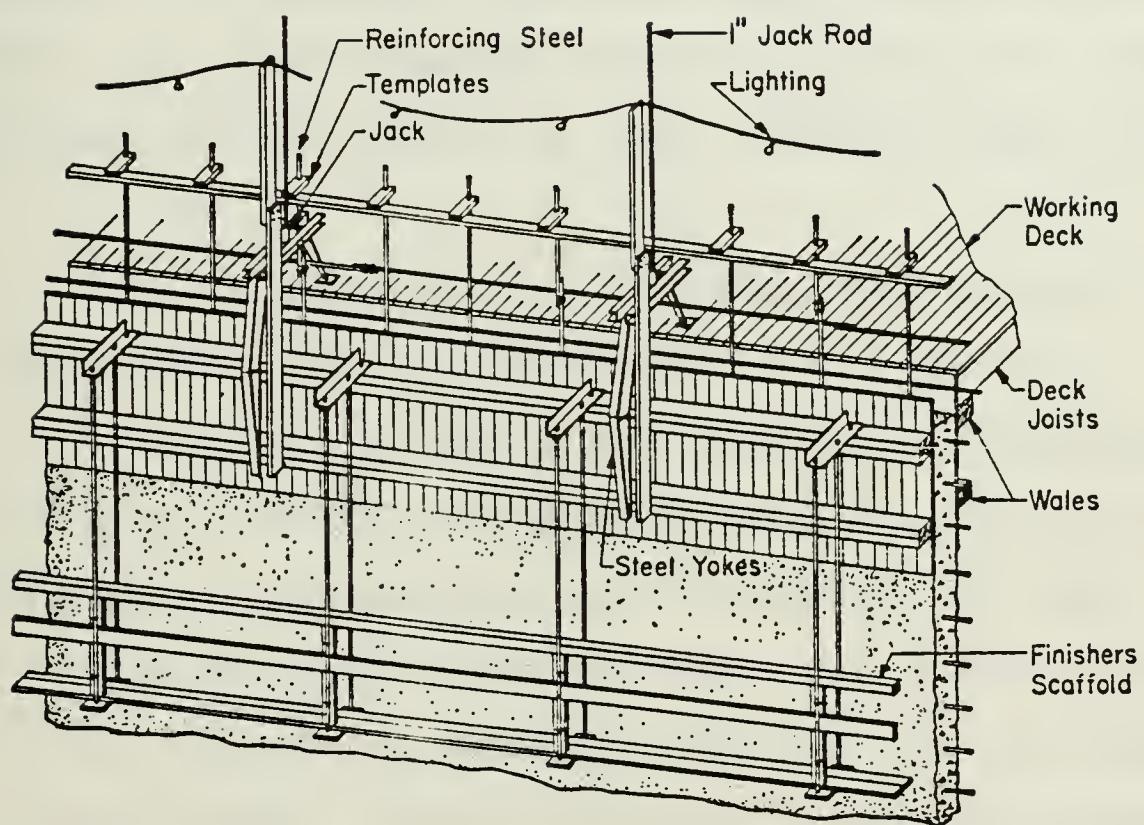


anchors for slab to core connections. Finally, installation of doorway forms, pipe sleeves, duct sleeves, and structural beam anchorage assemblies are performed on the working deck. The final level of the system is the finishing scaffolding where the finishing of the concrete to the building takes place. Also performed on the finishing level is patching of concrete where necessary, stripping of forms for openings, and installation and welding of beam bearing brackets and attachment tees. (7-2) (see figure 3-2)



Figure No. 3-2\*

### SPECIAL TECHNIQUES



\* Camellerie, J. F. , Slipform Details and Techniques,  
Journal of the American Concrete Institute, 1959, 1137.



### Control systems

Temperature changes during the process of forming, affect the rate of setting of the concrete, causing variations in the frictional resistance between the concrete and the sheathing which may cause the deck to be skewed. Maintaining the deck level during the process of forming is an important item which must be considered during the initial planning stage of the project. Common practices in the industry to check the deck level include:

1. Check position of jacks against hacksaw cuts previously made in jack rods at 1-ft intervals.
2. Use of a water-level system which consists of a central reservoir and plastic tubes placed at strategic locations and connected to the reservoir by hose.
3. Check by transit on deck. This can only be done while the deck is stationary which limits this methods effectiveness. Such a check can and should be made at the end of the process for final levelling.
4. Vertical tape measures from fixed points. This method is again only usable while the forms are stationary. (3-1136)

Deck levelling can be accomplished by the manipulation of individual jacks by an experienced superintendent.



Strong winds coupled with varying frictional resistance can result in the structure being formed out of plumb.

Correction for plumbness is difficult and can be done only under the supervision of a foreman highly experienced in slipform work. The forms must be set up plumb and true and properly braced. To check walls or piers for plumbness during work, the following methods are employed by the industry:

1. Targets painted on at least three sides of the structure in sets of two. Each set consists of one target painted on the moving form and one target vertically below painted on the base of the wall.

Periodic sights are taken to insure the line connecting the two targets remains vertical.

2. Plumb bobs dropped from several predetermined points on the deck to points previously marked on the base slab.

3. Check measurements between center lines diagonals, etc. (3-1135)

### Vertical\_slipform\_construction\_practices

#### Experienced\_supervision\_and\_crew

The importance of an competent and experienced supervision and journeymen can not be overemphasized in the



slipform system. Although the the maximum rate of progression must be carefully predicted and planned for, the actual rate must be controlled by an experienced field superintendent who is qualified to make such adjustments as changing field conditions inevitably require. The forms should be designed and built by individuals experienced in slip form work. The superintendent must see that the operation is not proceeding to quickly as to cause "blowouts" or soft concrete falling out from under the forms, nor so slow as to cause "lifts" or concrete sticking to forms and ripping away from the below. (7-3)

### Concrete

A vertical slipform system does not require a special type or mix of concrete; however, there are some considerations which are peculiar to the system. The horizontal pressure developed on the sheathing must be maintained within the design parameters of the forms. The main factors affecting lateral pressure are temperature and the rate of filling. Other factors that must be taken into account are the amount of cement in the mix and the water cement ratio, and whether or not the concrete is consolidated by mechanical vibration. The faster the forms are filled and the lower the temperature, the greater will be the pressure because the concrete does not have ample time to set and relieve the pressure. Concrete at a low



temperature will set slowly, and for a given rate of movement the pressure may be 50 to 75 percent greater than when the temperature is twice as high. Concrete in heavy walls and piers, in which large stones or "plums" can be embedded, will always exert less pressure on the forms than when the stones are omitted, because true hydrostatic pressure will not exist. Rich mixes exert greater pressure than lean ones and wet concrete greater than dry concrete.

The slump should be between 3 and 6 in. depending on temperature, wall thickness, reinforcing congestion, and anticipated rate of movement. Control of concrete slump should be placed in the hands of the field engineer or superintendent who should vary the slump without change to the water cement ratio. Aggregate size should be limited to 3/4 in. for walls less than 8 in. thick and 1 in. for walls 8-12 in. thick. Care must be taken to spade or vibrate concrete thoroughly. (3-1137)



### Placing\_Concrete

Concrete is placed in horizontal layers of from 6 to 10 in. in thickness, the 6 in. layers being the most desirable. Not more than 1 hour should elapse between the placing of successive layers of concrete; this will insure proper bonding between layers and prevent spalling of partially set concrete. If delays occur, concrete should be placed in layers less than 6 in. thick rather than allow the time between placing successive layers to exceed 1 hour. Set may be retarded by substituting crushed ice for water or accelerated by heating the water. Decks must be kept broom clean at all times and concrete must not be allowed to accumulate around forms.

### Detailing\_and\_placing\_of\_reinforcing\_steel

Detailing and placing of reinforcing steel varies only in the following respects. Vertical bars are limited in length to prevent excessive lash from the wind. Verticals over 20 feet long should not be used unless a second deck is planned over the work deck for use by the reinforcing crew, since bars weighing more than 35 pounds are difficult to handle from the bottom end. During construction vertical steel must be held in place by appropriate templates and care should be taken that required cover is maintained. In detailing vertical reinforcing steel splices should be staggered at various levels so as to equalize the burden on the iron crews.



Horizontal bars should also be limited in length to enable the steel to be threaded through the vertical steel and the form yokes. Lengths should generally be limited to 18 to 20 feet and when hooks are required 10 feet is a better figure. The use of 90 degree hooks instead of standard hooks considerably facilitates placing. Horizontal steel should be designed in full layers, to facilitate placing and inspection, and different spacing of horizontal steel at any one layer should be avoided. Whenever possible, horizontal steel should be spaced at 6 to 18 in. on centers with the spacing nearer 12 in. being the most desirable. Bars 3/4 in. in diameter and smaller are generally preferable to larger sizes. (3-1134)

#### Curing and Finishing "formed" surfaces

To the eye and touch of an experienced superintendent the condition of the concrete when first exposed below the sheathing indicates appropriateness of the rate of movement, the structural stability of the wall and the level of safety of the operation at any time. (5-2) One indication that the concrete has cured sufficiently is a finger pressed into the concrete at the point of exposure should leave an imprint about 1/16 in. deep on removal. Finishing provides no problems in the vertical slipform system. The concrete is in excellent condition for a float and brush finish. The finishers work comfortably from the hanging scaffold. The absence of joints result in a finish



that is durable when exposed to the weather. One curing method is the use of membrane-type curing compounds applied directly from the finishers' scaffold. Another method is water curing using water lines hung from the forms. If water curing is used, fog spray is recommended to prevent erosion or discoloration. (5-4)



### Advantages/Disadvantages

The primary advantages to vertical slipform systems are their economy and speed. Construction proceeds at approximately twice the speed of fixed forms. The reduced construction time produces reduced cost. Jointless structure eliminates water intrusion and reinforcement corrosion. The elimination of horizontal joints enhances the structure's appearance.

The primary disadvantages of the system are anything that could reduce the rate of movement, ie, placing of welding plates, inserts, openings and pockets, changes in wall location and sizes, proportionately reduces the savings inherent in the system. Lack of height in a structure, generally taken to be less than 40 feet, will not provide significant cost savings from this system. Walls can be stepped but not tapered. The structures cannot have any perpendicular structures originating from the surface to be formed with the system. An experienced crew and superintendent are required for the job which translates into high labor costs.



## Chapter IV

### Horizontal Concrete Pavement- Conventional and Slipform Technique

#### Introduction

The first major concrete pavement built in America, a 220 feet long and 10 feet wide strip, was constructed in the city of Ballefontine, Ohio in 1891. (8-551) The first concrete section on a rural road was placed October 10, 1908, it was 11 miles long, 24 feet wide and 5 inches thick. (8-551) In the 1920's a mechanically powered track-type single drum paver was produced. In the 1930's the dual drum paver was introduced. After World War II, a few significant changes were made in the process of constructing concrete pavement. Two major breakthroughs in paving equipment were gaining acceptance. These were the slipform paver and the central mix plant.

Although the first slipform paver was manufactured in 1949, it was not until 1955 that any appreciable pavement was constructed by this method. In that year approximately 20 miles of pavement 20 to 22 feet wide and 6 inches thick were constructed on secondary roads in Iowa. In Wyoming and Colorado the slipform paver was put to work on primary and interstate projects. In the presentation to follow both the form type and slipform paving method will be discussed.



## Formtype Pavement Construction

Pavement performance depends to a large extent upon the quality of the materials used and the techniques employed in construction. (9-339) After compacting the subgrade or sub-base, the top surface underlying the pavement should be graded to the required surface level. When the final preparation of the subgrade is completed, the surface should be covered with reinforced waterproof paper or polyethylene sheeting. (9-340) Sometimes the surface is sealed with a bituminous material blended with a thin layer of sand. This inhibits the escape of cement paste into the subgrade layer and will reduce the friction between the slab and the subgrade. Another alternative is to wet the surface just before the concrete is cast in order to prevent water from being absorbed from the concrete when it is placed. This alternative should only be used where the subgrade has a hard smooth surface.

The next step, in traditional concrete pavement construction, is to lay the side forms for casting the concrete. A typical paving form is a complex steel channel section, with a face the height of the proposed pavement thickness, a wide flat base for stability, an upper rail to carry equipment, reinforcing gussets, and provisions for fastening to the ground with spikes. (10-101) Wedges are driven and locked between spikes and forms for fine adjustments of alignment. Length of sections is 10 feet or



more. Steel thickness is anywhere from 3/16 to 5/16 inches and weight per foot is in the neighborhood of 12 to 45 pounds. The face of the channel holds the concrete, while the rail-like top provides the strike off level for the surface and usually is a track for finishing machinery. Twisted, bent, dented, or encrusted forms should be discarded. Forms are usually removed approximately 24 hours after the concrete is placed, if standard cement is used. This is sufficient time for hardening to reduce breakage; however, extreme care must be exercised when separating forms from concrete. Forms should be slightly lubricated before use to reduce or prevent sticking. Forms should be inspected and thoroughly cleaned before reuse.

(10-100) It should be emphasized that a large percentage of the major irregularities in a concrete pavement surface can be attributed to the use of defective forms which are inadequately placed. (9-404) After all the forms have been set and the fine grading is completed, just prior to concrete placement, the forms should be checked for line and grade. If the elevation of the slab is not critical this can be done by eye. (8-554) However, if the slab elevation is critical the top surface of the forms should be checked with an engineer's level at 25-30 feet intervals. After this procedure the surface of the subgrade should be checked for depth using the tops of the forms as a reference. (8-554)



### Drum\_Pavers

Until rather recently most concrete for pavement was mixed on the job site. Now more mixing is done in central plants. The drum paver or concrete paving machine is usually crawler mounted and operates on the subgrade. A wide shallow hopper is hinged to the front where dry cement and aggregate, proportioned at the batch plant, was dumped by the batch truck. The loaded hopper, capacity of 1.5 cubic yards, is raised to dump its load into the revolving drum. A measured quantity of water is added, the concrete is mixed for a specified time and the drum discharges into a bucket that can be moved inward and outward on a horizontal swinging boom. The boom and bucket are controlled to place the concrete at the desired location. This technique proved too slowed, however, so spreaders were developed.

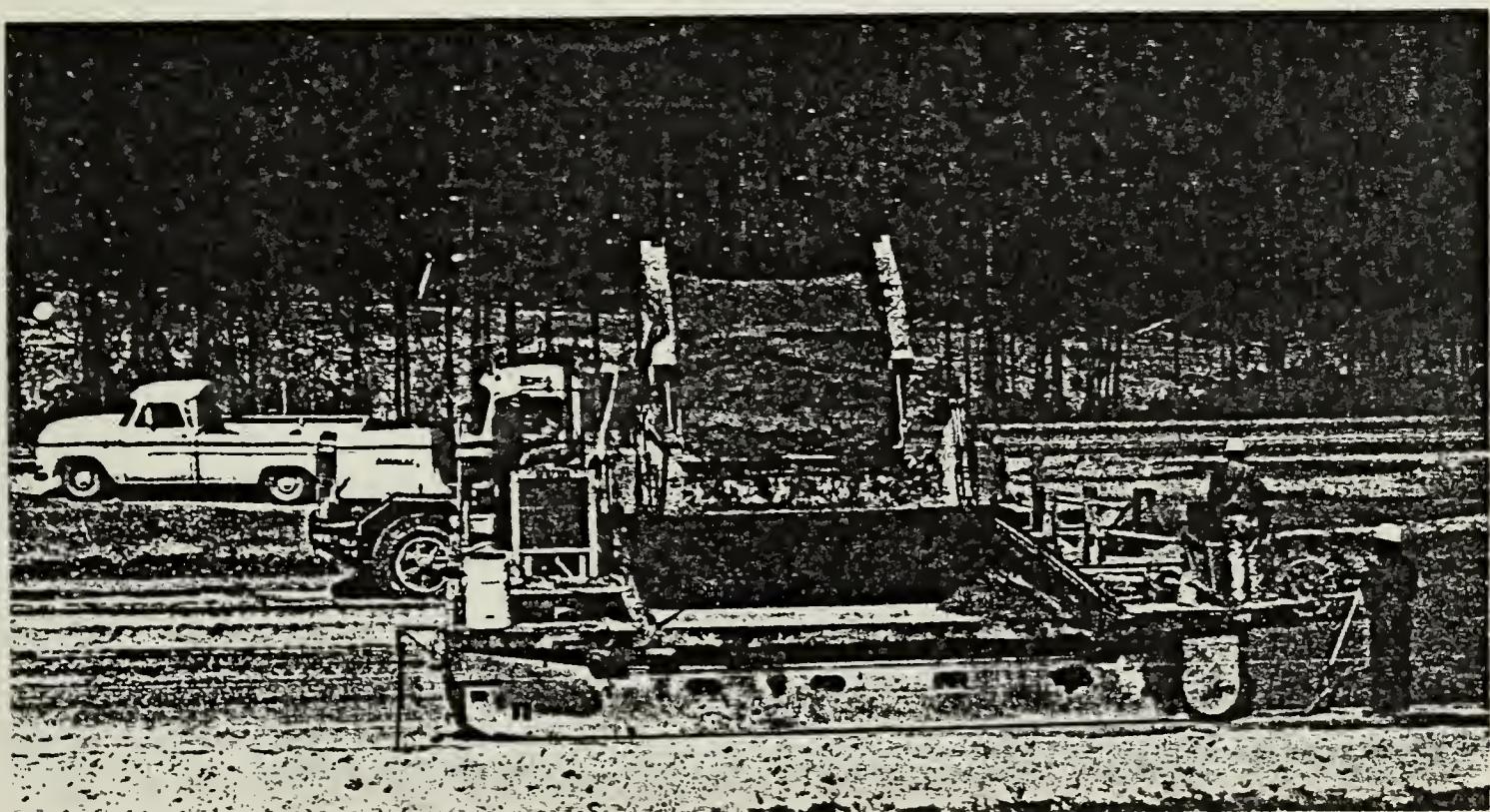
### Spreaders

A spreader is a distributing machine which accepts mixed concrete in full trucks loads and spreads it between the forms. There are a number of types including the hopper spreader with capacities up to 8 cubic yards. Hopper spreaders are loaded by side dump trucks and move back and forth across the paving strip spreading concrete to a pre-selected depth. A horizontal auger is a basic design for spreading hauled-in concrete. (10-103) With side



dump trucks and a side hopper, it may be a continuous screw. If the hopper is in the center, for rear dump trucks, the two sides of the auger are pitched oppositely. The auger is positioned and speed regulated to leave the surface of the wet concrete lumpy and a little higher than the desired surface. It is followed by a front screed that pushes and cuts it down to almost final level. A rear screed, a wide plate that has either side to side or vibratory motion as it advances, makes the concrete flow into exact contact with its lower surfaces. (10-103) (see fig. 4-1)

Figure 4-1\*



\*Baker, R. F., L. G. Byrd, and D. Mickle, Handbook of Highway Engineering, Van Nostrand, Reinhold Co., New York, 1975, p 110.



### Vibration

Vibration is important in the consolidation of practically all concrete pavements. The effect of the vibration is to cause the concrete to become temporarily more liquid, and to supply it with an impetus to flow freely into restricted spaces. (10-106) Properly vibrated concrete should pack smoothly against forms, and under and around reinforcement without voids. It leads to desirable low slump concrete the fluidity otherwise obtained only with high slump, lower strength mixtures. If vibration is continued for too long or the incorrect technique is employed, the concrete will segregate. The liquid will stay on top and the coarse aggregate will sink adversely effecting weather resistance and strength. Typical vibration methods include surface plates, screeds, or cylinders immersed in the concrete. (10-106)

### Finishing

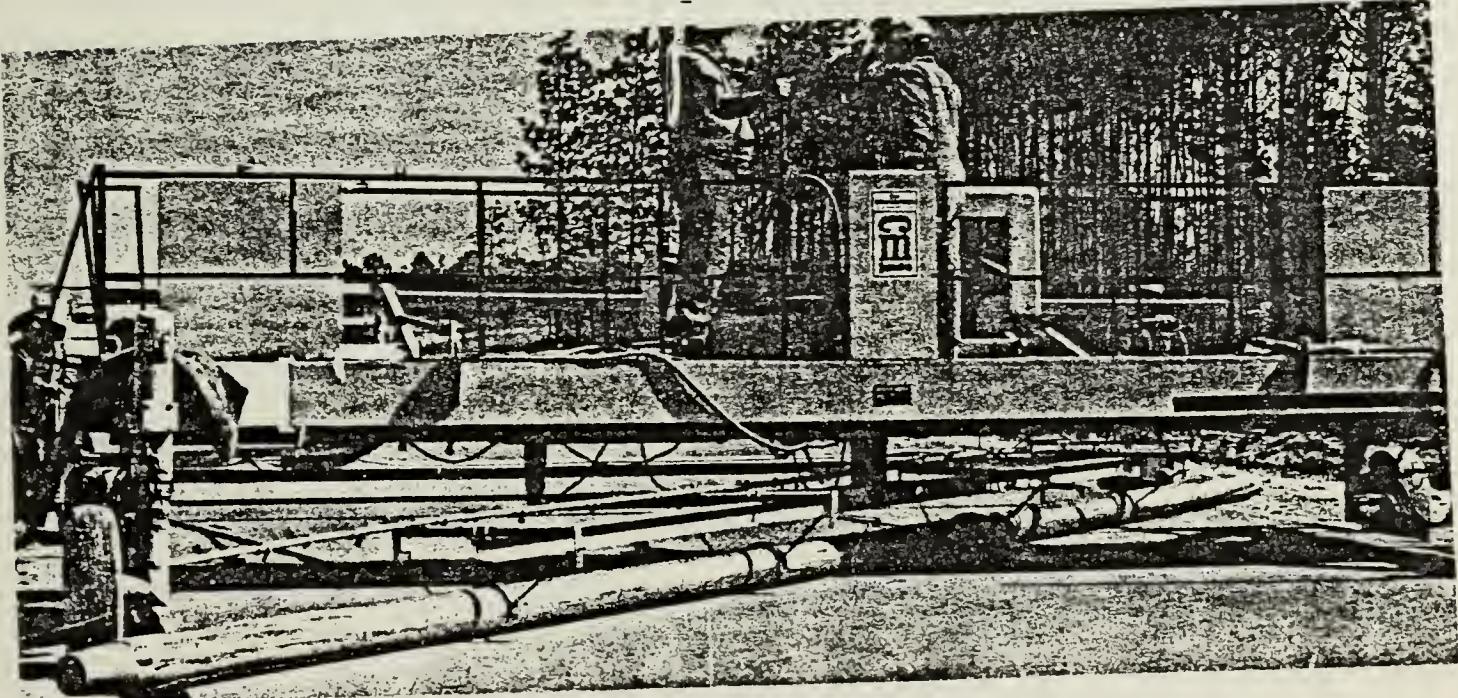
Additional operations to correct any deficiencies and provide the desired finish is called finishing. Finishing may include a float device, moving in strokes forwards and backwards as a carriage moves it from side to side, or a diagonal tube finisher is a very long aluminium tube about 8 inches in diameter, which is moved back and forth by hydraulic controls until finish grade is satisfactory. (see fig. 4-2) Final finish may be provided by a sheet of



burlap dragged longitudinally, a long handled, stiff-bristled brush pushed across or other means. (10-106) Depth of brush pattern may be varied by type and spacing of bristles and the amount the concrete has set. The ridges between bristle grooves should not slump or flow together (concrete is too green) nor ravel into sand or crumbs (set too much). (10-106) Much deeper, sharper grooves may be cut by sets of diamonds or carbide saws after the concrete has set so that no pieces of aggregate will be loosened or at any time after that during the life of the pavement.

(10-106)

Figure 4-2\*



\* Baker, R. F. , L. G. Byrd, and D. Mickle, Handbook of Highway Engineering, Van Nostrand, Reinhold Co., New York, 1975, p. 112.



### Curing

Water must not be allowed to evaporate from the surface until hydration has progressed far enough along to lock the necessary amount into the concrete. Curing is the hydration process or the means taken to prevent loss of water. The hydration period for standard mix cement mixtures may vary from 3 to 10 days. The two methods most often used are a waterproof membrane or polyethylene sheets.

The membrane is a chemical that is sprayed mechanically onto the concrete to form a thin film that stops evaporation. The substance itself is transparent, but it is usually mixed with a white dye that permits verification and accuracy of application, and keeps the concrete cooler by reflecting the sun's rays.(10-106) The membrane wears off naturally under the wear of traffic flow. The sheets are heavy gauge white polyethylene somewhat wider than the pavement and very long. The sheets are rolled for storage and transportation and unrolled on the concrete behind the finishers, either by hand or machine. The edges are weighted with loose dirt, stones or scrap. After curing is complete the weights are removed and the sheets are re-rolled to be relocated to the next section of pavement.



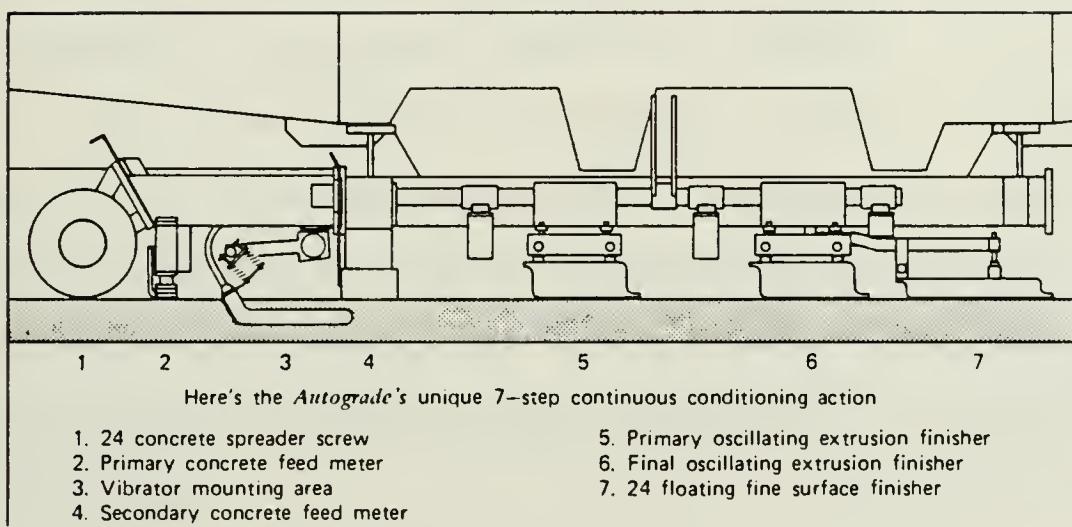
## Slipform paving

In slipform paving, the forms are physically attached to the paving machine and move with it, leaving the slab unsupported. These forms may be 16 to 48 feet long and pavers may move at a speed of 6 to 12 feet a minute. The slip-form paver performs a number of different operations in succession. These may include some or all of the following: receiving the truck delivered concrete, spreading the concrete to full width, compacting and eliminating voids, striking off and leveling the surface, installing reinforcements, surface finishing and placing membrane or polyethylene sheets for moisture retention during curing.(10-108) The subgrade must be prepared to sufficient width to accomodate the tracks of the paver outside of the paving lanes. Subgrade accuracy is vital to smoothness of finished pavement because the paver operates directly from on it. If the paver does not have automatic grade controls, any irregularities in the base is reflected directly in the pavement surface. If there are automatic controls, irregularities will activate these monitors and problems of overcompensation or undercompensation may arise.(10-108)



Figure 4-3\*

Autograde "CC" Slip-form Paver  
Model SP-24-SF



\*Sargious, M., Pavements and Surfacings for Highways and Airports, Halsted Press Books, New York, 1975, p 340.



### Concrete and Reinforcement Placement

The wet concrete may be supplied into a hopper by side dump trucks or onto the subgrade by rear dump trucks. Spreader boxes attached temporarily to the truck while dumping prevent segregation of the concrete that might result from uncontrolled placement on the subgrade. A substantial advantage of using the subgrade for truck traffic is that there is room for two or more trucks side by side when paving covers two lanes or more. This usually allows for smoother traffic flow and the capability to dump more trucks in a given time period. (10-109) Reinforcement is customarily placed by a two-layer method. A slip-form paver, with forms set 2 or 3 inches in from the edges, places 2/3 of the pavement depth. Reinforcing steel and dowels are placed by hand or machine. Subsequently, a second paver with forms set for full width then spreads concrete over and besides the first strip to form a finished slab.



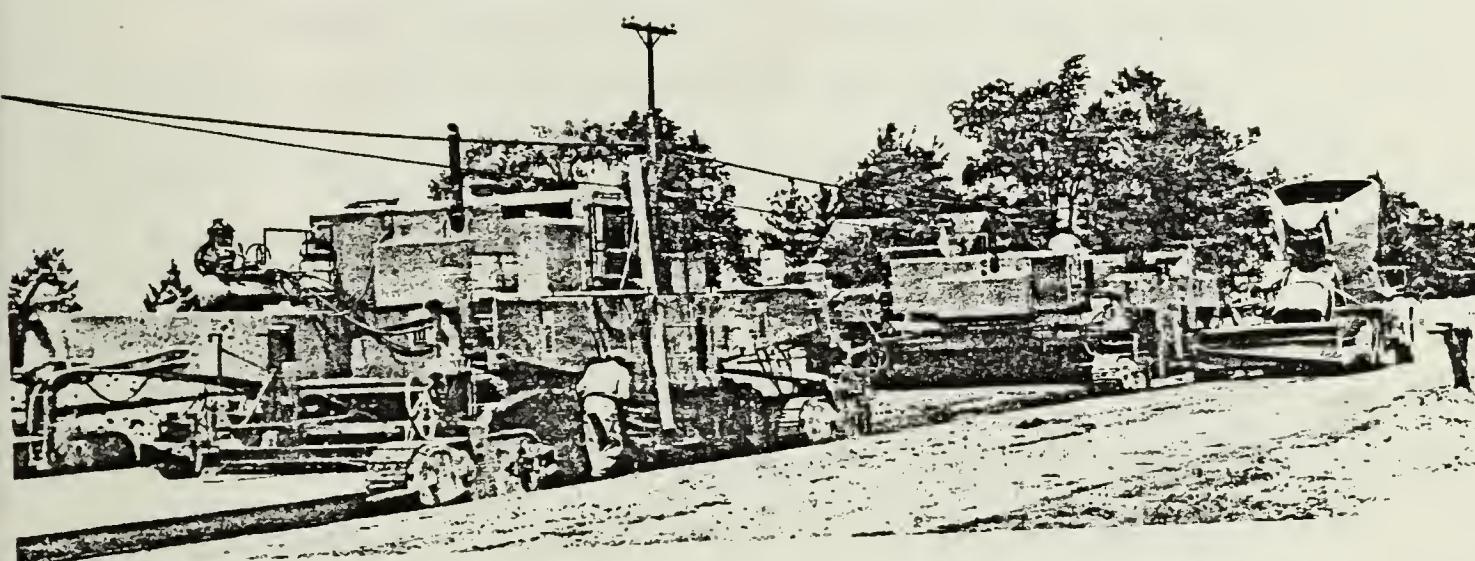


Fig. 4-4\*

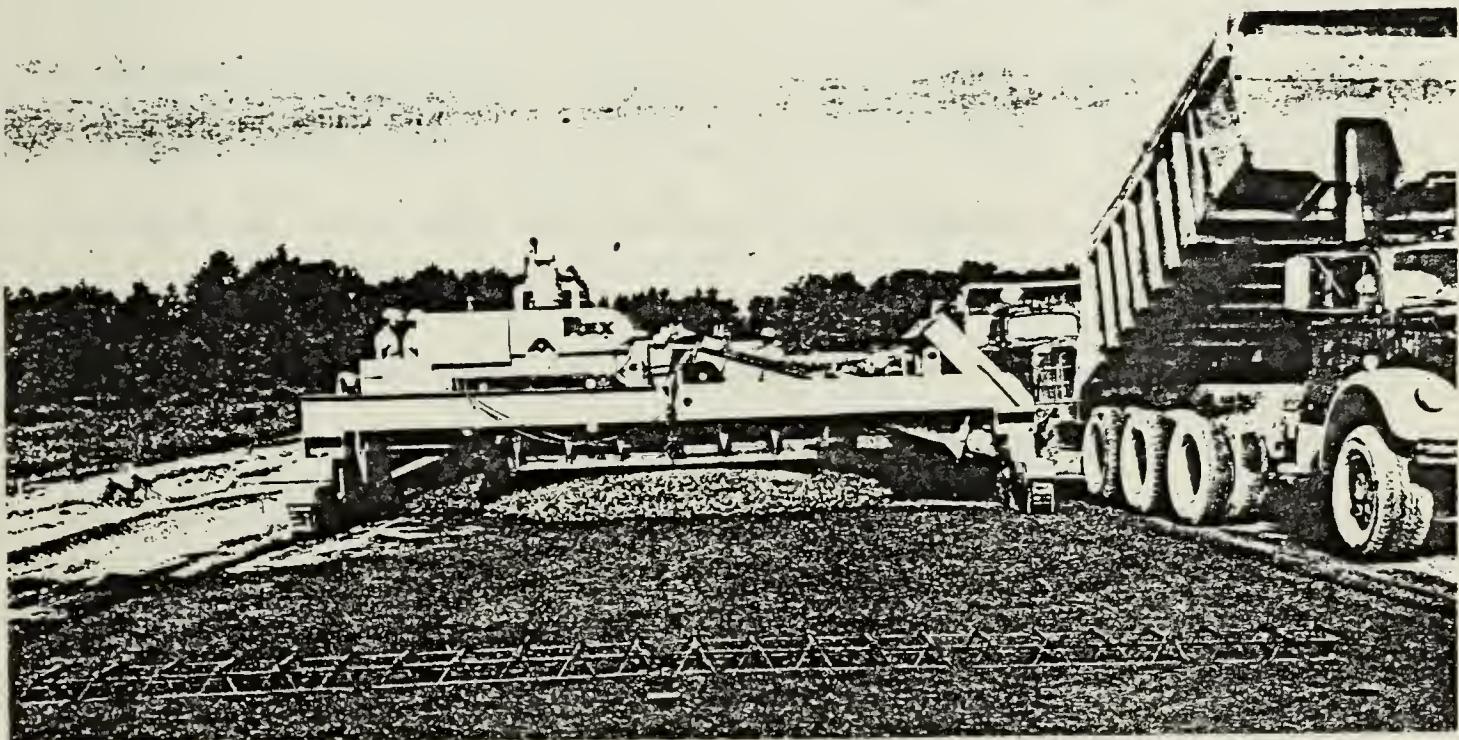


Fig. 4-5\*

\*Baker, R. F., L. G. Byrd, and D. Mickle, Handbook of Highway Engineering, Van Nostrand, Reinhold Co., New York, 1975, p. 115.



### Horizontal\_Slipform\_Pavers\_Advantages

Probably the greatest advantage of the horizontal slipform paving is the economy of operation. An approximate savings of 50 to 75 cents per square yard translates into more highway for less public dollars. The initial capital investment for conventional paving equipment, including paving machines, forms and the equipment for the forms is approximately 50 per cent greater than slipform equipment. Fewer men are needed with slipform equipment which is a direct reduction in labor costs. The typical pavement project is completed more rapidly, which is a reduction in labor and equipment time and permits the contractor to complete more projects in the same amount of time. On the whole, pavement constructed with slipform pavers provide an substantially improved ride over conventional pavements. Increased strength and better uniformity from one area of the pavement to another is achieved due to the better mix control required in slipform paving. Operation efficiency is enhanced by using one machine to accomplish the purpose of five machines in conventional paving. With a reduction in machinery on site, less manpower is required to control and supervise the operation, maintenance, and security of the equipment. Slipform pavers are versatile and can be used to accomplish any type of pavement project including : large projects or small projects.



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thick (12-in) pavements or thin (6-in) pavements.  
new construction or repair work.  
mainline or ramps.  
level terrain or mountainous terrain.  
rural areas or urban areas.  
wide (48 feet) or narrow (14 feet) pavements.  
with or without reinforcement.  
for plain surfaces or crowned surfaces.  
with on-site or central batch concrete.

#### Disadvantages of Horizontal Slipform Paving

The slipform paver also has several disadvantages associated with its operation. The most important and least obvious of which is the quality of personnel required. Extensive training is required of field supervisors, operators and mechanics. Field supervisors must have technical training to familiarize themselves with the idiosyncrasies of the equipment with which they are working. Operators need several months of training with other experienced operators. This requires careful planning ahead, so that new men are available as they are needed. Care and maintenance of the slipform paver must be meticulous and cyclical. Each time the paver is relocated it must be inspected for misalignment, warping, breakage, and inadvertent changes in setting of control elements. Specially trained mechanics, well versed in slipform pavers, must be available at the job site prepared to handle any mechanical problems which may arise. Otherwise, the uniformity of the pavement cannot be insured. The inadequate preparation of the subgrade will result in a rough pavement. Untreated base materials are easier to



prepare than cement treated materials due to the fact that they can be reworked until correct. However, treated bases provide a more stable all weather working platform. The uniformity of the concrete mix is key in achieving the performance desired of the pavement. High-frequency vibrators operating at 3000 to 5000 vibrations per minute have helped ensure adequate density of the concrete. An additional problem associated with concrete uniformity is edge slump.



## CHAPTER V

### THE NAVAL CONSTRUCTION FORCES

#### Introduction to the Department of Navy

To thoroughly understand the mission of the Naval Construction Forces(NCF) it is first necessary to have an overview of the Department of the Navy(DON). This overview may be simplified significantly by the employment of organizational charts. As depicted on figure 5-1 the operational, support and administrative components of the DON report to one of three offices. For the Marine Corps organization, all forces report to the Commandant of the Marine Corps. For all the Navy organizations, all forces and activities report to the Chief of Naval Operations(CNO). The Secretary of the Navy represents the ultimate authority in the DON. As depicted on figure 5-2, beneath the CNO is the Chief of Naval Material, who until quite recently was responsible for the five system commands along with the all large weapon procurements for the DON. Among those five system commands lies the Naval Facilities Engineering Command(NAVFACENGCOM). Officers of the Civil Engineer Corps(CEC) who administer the work of NAVFACENGCOM are commissioned officers having special technical qualifications. They are engineers, planners, estimators, architects, analysts of the Navy's shore facilities, and

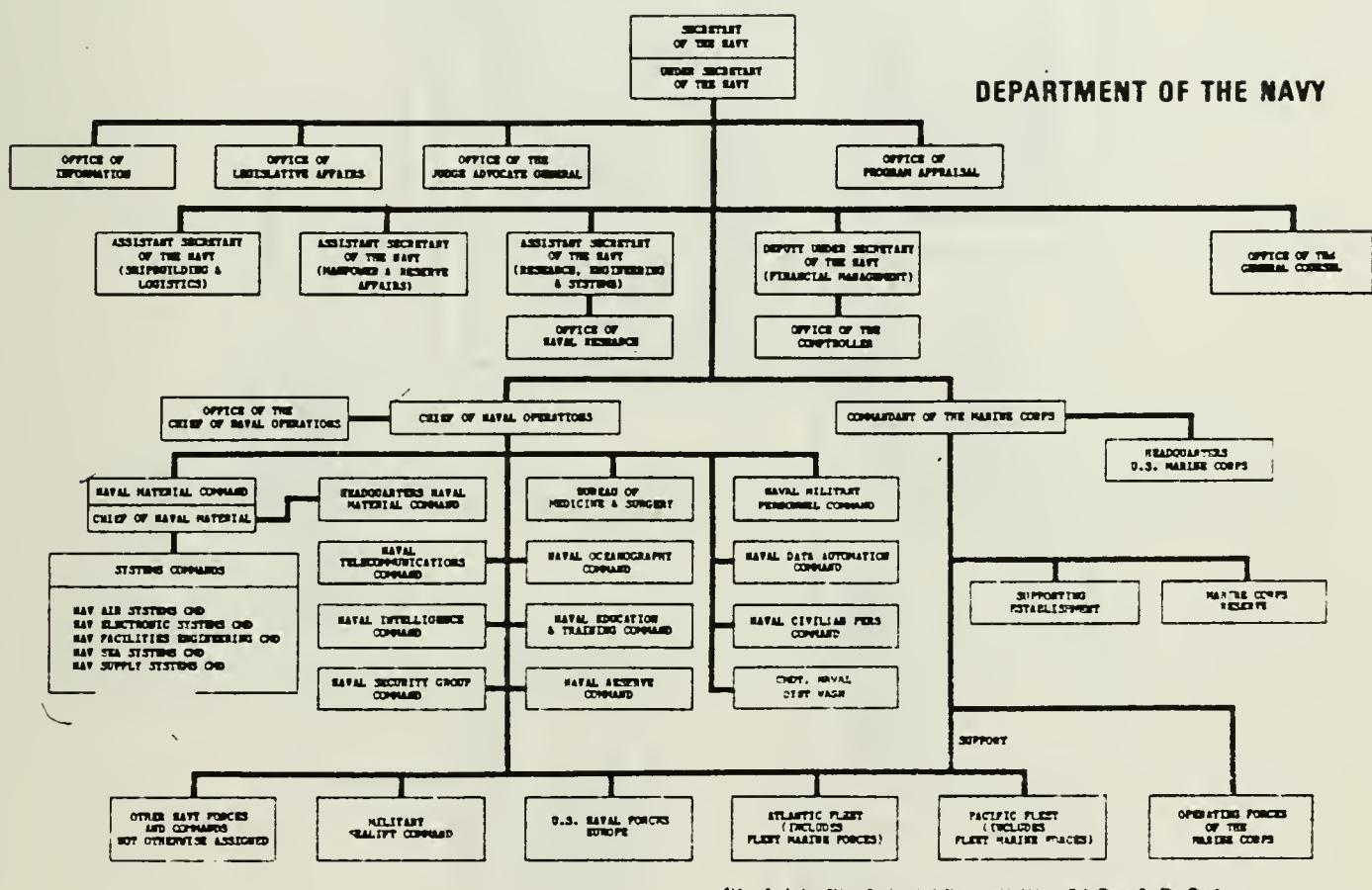


overseers of the construction and maintenance of the shore establishment. To facilitate the accomplishment of its gigantic mission, NAVFACENGCOM has divide the World into six divisions and established regional Engineering Field Divisions (EFD) to oversee all Naval facilities activity in that region. (see figure 5-3) Each EFD is organized to accomplish its mission of Facilities Acquisition, Management and Planning for that region. (see figure 5-4)

The Commander, NAVFACENGCOM is also the Chief of Civil Engineers and as such exercises technical direction over the NCF, generally known as the Seabees. NAVFACENGCOM also has support responsibility of commands and organizations established as separate activities of the DON whose primary function is the organizing and equipping of the NCF.



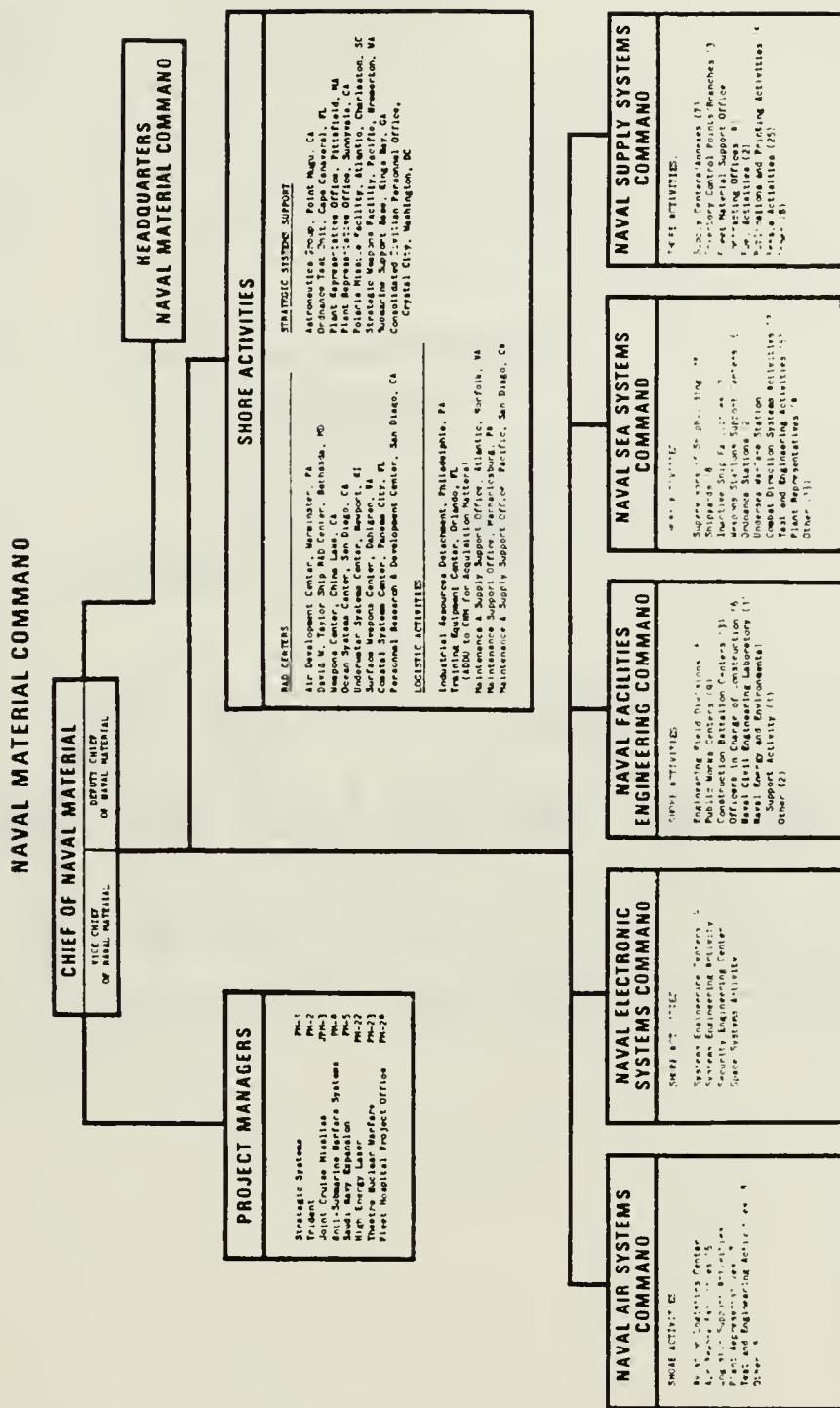
Figure 5-1\*



\*U. S. Department of the Navy, Civil Engineer Corps Officer School, Public Works Manual, Port Hueneme, California, 1982, p 1039.



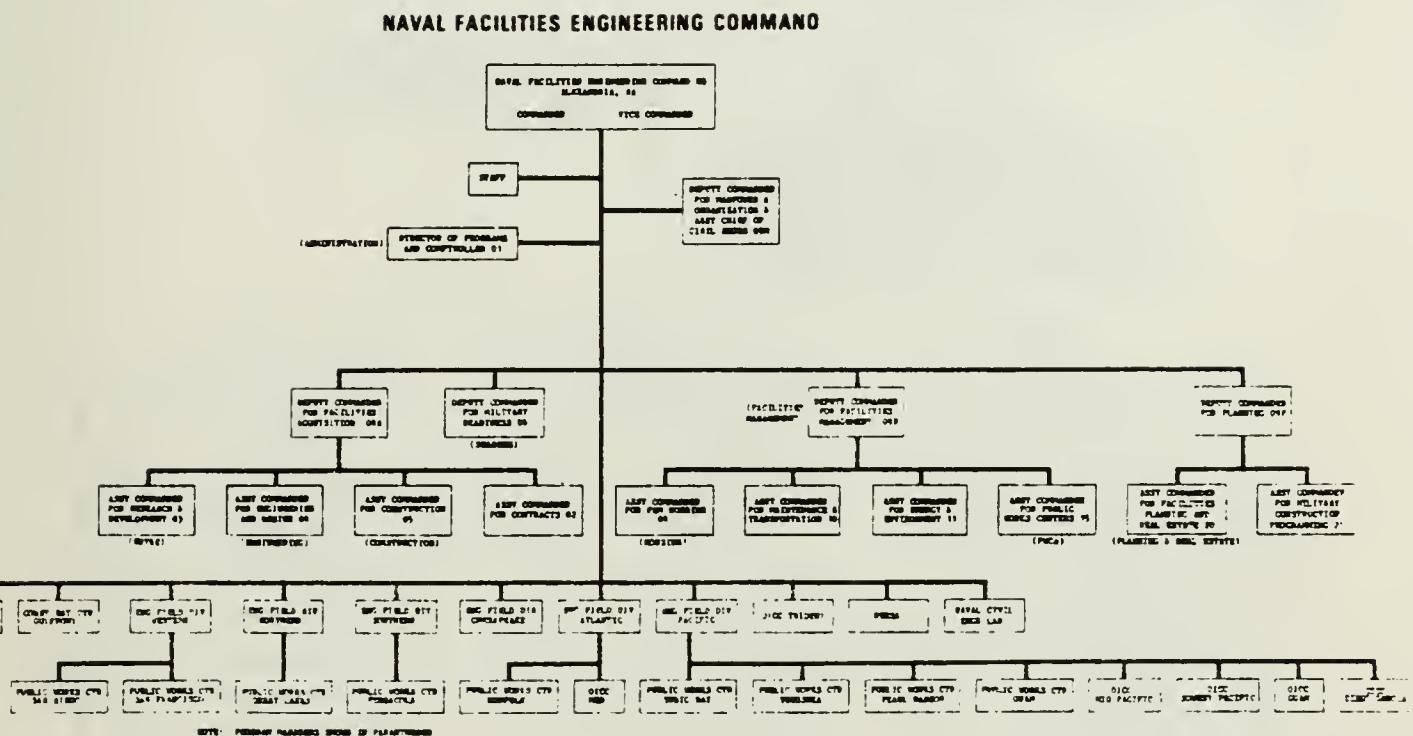
Figure 5-2



\*U. S. Department of the Navy, Civil Engineer Corps Officer School, Public Works Manual, Port Hueneme, California, 1982, p 1039.



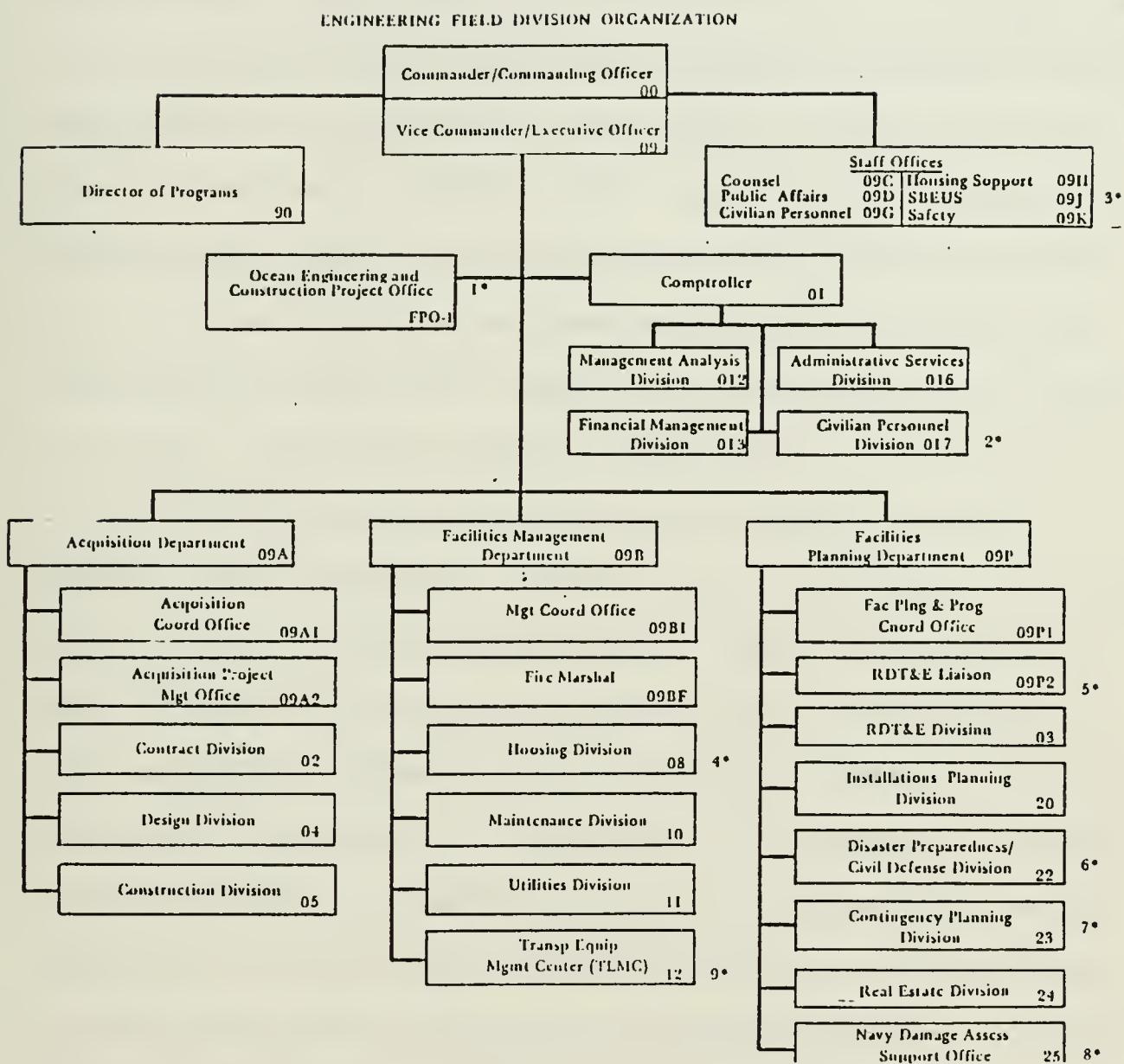
Figure 5-5



U. S. Department of the Navy, Civil Engineer Corps Officer School, Public Works Manual, Port Hueneme, California, 1982, p. 1040.



Figure 5-4\*



U. S. Department of the Navy, Civil Engineer Corps Officer School, Public Works Manual, Port Hueneme, California, 1982, p. 1041.



## History of the Seabees

Although the Seabees originated in World War II, a small start was made on the Seabee concept in World War I. At the Great Lakes Naval Training Station, the urgent need for construction men caused the activity to assign recruits with previous construction experience to one of the 18 Training Regiments, (12th). This regiment then became the skilled labor pool for the station Public Works Officer. A force of some 600 Navy men was especially recruited and organized to construct a large, high powered radio station in France. With the advent of World War II, the services of contractors and their civilian employees engaged in building naval projects overseas could not be utilized for construction work in combat zones. Under military law their status as civilians prevented them from offering resistance to an enemy without becoming liable to summary execution as guerrillas in the event of capture. Further, civilian workers lacked the training necessary to defend themselves. Admiral Ben Moreell, the Chief of the Bureau of Yards and Dock (predecessor to NAVFACENGCOR), therefore proposed the creation of a construction force within the Navy to meet the needs for uniformed men to perform construction work in combat areas. (11-150) Three Naval Construction battalions (NCB) were authorized in January 1942. The name "Seabees" derives from the initials of the term "construction battalions". The number of NCB rapidly



rose in number to about 150 regular, some special purpose battalions and a larger number of smaller miscellaneous units. At the peak, about 250,000 men were serving in the Seabees in August 1945.

After World War II the Seabees became a permanent part of the fleet. Two amphibious construction battalions (ACB) were still assigned to the Fleet, the 103rd NCB was still doing maintenance work on Guam and various detachments were spread around the World. With the advent of the Korean War, the Seabees of ACB1 supported the amphibious landings at Inchon and CBMU 101 supported the Marine Corps elements ashore in the construction of airfields and roads. A reorganization of the Seabees into Naval Mobile Construction Battalions (NMCB) , in addition to the existing ACB, was planned before the Korean War and implemented during the War. In 1951, the Seabees started the construction of the NAS Cubi Point in the Phillipines. The earth-moving project is considered by many as second only to that of the Panama and Suez Canals among the World's great engineering works.

Seabee teams first entered Vietnam in 1963 as Civic Action Teams, but later additional teams were used to provide construction support for Special Forces troops. In May 1965, Marine Corps troops landed at Chu Lai, Vietnam, supported by elements of ACB1. (10-150) Within a year, all 10 existing NMCB's had been rotated to Vietnam on a 8-month



in country and 6-months at homeport for training. All 21 NMCB's rotated into Vietnam with 12 in country at a time during the peak. The 3rd Naval Construction Brigade and 30th and 32nd Naval Construction Regiments were formed to operationally control the Seabees' efforts. Two Construction Battalion Maintenance Units (CBMU) were formed and deployed to provide maintenance and operation support for existing bases and additional Seabees were attached to the Public Works Department of the Naval Support Activities at Danang and Saigon. Currently, the Seabees are engaged in operations in many areas of the world, but probably the most challenging assignment just recently completed was the construction of a communications station on Diego Garcia Island in the Indian Ocean.

#### The Seabee Organization

A battalion is the fundamental unit of the Seabee organization and is comprised of four construction companies plus a headquarters company. The four construction companies provide all the necessary skilled labor for any construction project, while the headquarters company provides the logistic support required by the battalion. An NMCB is an independent, self-sustaining unit organizationally designed to operate alone with its complement of 20 officers and 1000 men. It can accomplish a large variety of construction missions ranging from roads,



bridges, airstrips, fuel storage tanks, water supply system, and electrical installations, to erecting any type of building. The composition of an NMCB necessarily represents a large cross section of the building trades—carpenters, plumbers, electricians, engineers, surveyors, heavy equipment operators and masonry workers. The function of a CBMU is upkeep and maintenance of completed bases. It is also equipped to accomplish relatively light construction projects.

#### The Construction Battalion Unit

For years the Seabee shore duty billets have been scattered throughout the shore establishment with little apparent logic. Skilled Seabees had to serve ashore after years at sea so every opportunity was taken to obtain Seabee shore billets regardless of functions assigned. Consequently, until 1969 Seabees could be found doing almost any job but rarely were their jobs related to their training and skills. Commencing in late 1969, the Chief of Civil Engineers obtained approval of the Chief of Naval Operations and the Secretary of the Navy to organize Construction Battalion Units (CBU) at centers of Naval Activity, to more effectively utilize these Seabee shore billets. The CBU provided an excellent vehicle to improve Seabee peacetime training and enhance their readiness posture. The CBU are now taking the lead in the Self-help program in the immediate geographic areas where they have



been established. The typical CBU is platoon sized at 45 men and one Civil Engineer Corps Officer as Officer-in-Charge. It is equipped with 20-30 pieces of heavy construction equipment, basic tool kits, weapons and combat gear. It is designed to be self-sufficient for construction operations with almost all assigned personnel capable of productive labor.

### Seabee Training

The primary purpose of training Naval personnel is to produce a combat Navy which can maintain control of the sea and guarantee victory. Victory at sea depends upon the state of readiness of "All Hands" to perform tasks assigned to them in accordance with the needs of the Navy. The primary job of the Seabee is to build, but based on the theory that they cannot build unless they control the jobsite, all Seabees receive training in defensive combat tactics. Each company in a battalion organization is divided into combat platoons, squads, and teams (fire, machinegun, and rocket). As a self-sustaining unit, the NMCB in particular must be capable of self-defense for a limited time. Each battalion subdivision has a construction/military support billet. Platoons are organized into work crews that corresponds to the weapon squad organization.

The Builder rating, a position description that identifies a masonry worker in the Navy, in general terms



is required to plan, supervise and perform tasks required in the construction, maintenance and repair of wooden, concrete, and masonry structures, concrete pavements and waterfront and underwater structures. The largest concentration of billets, job positions, for Builder First Class (BUC1) and Builder Chief (BUC) are allotted to NMCBs. In a battalion a BU1 or BUC usually serves in a construction company as the supervisor of a construction crew. Crew sizes may vary based on the availability of manpower and type project involved. The BU1 or BUC is also expected to be involved in planning work assignments, initiating requisitions and keeping timecards. The BUC is also tasked with scheduling training courses to aid younger sailors advance. The BUC must prepare performance appraisal of subordinates as well as conduct personnel inspection periodically. The BUC and other senior enlisted personnel are tasked with numerous collateral duties which must be accomplished smartly if the individual has aspirations of further advancement.

#### Concrete Construction in the NMCB

The NMCB does very little work in concrete construction when the total amount of work in place is calculated for a period of time. The NMCB is an entity which must be able to move at little more than a moment notice with all equipment being transported by military aircraft or troop transport ship. The material used in the construction of roads.



buildings, or support facilities is by necessity the material readily available to the NMCB. Therefore, the requirement for experts in a specific area is not as great as the requirement for experts in many areas. All vertical concrete structures which are to be constructed by the NMCB are designed by structural engineers working at the EFD. These structures are designed to be formed conventionally using plywood sheets and two by fours. The reasoning for conventional forming in the NMCB is simple. First, the lack of expertise in the Builder rate associated with the slipform technique. Secondly, the lack of expertise in the EFD to design the structures to employ the the slipform technique. Horizontal "concrete" pavements constructed by the NMCB are designed by engineers in the field using whatever in situ materials are available. Variability of concrete properties is highly likely and subgrade construction is accomplished as well as possible. Often times, the surface is only temporary , making the necessity for superb pavement none existent. The question is raised is there a need to acquire the expertise in the EFD or the NMCB to permit the use of slipform technique in the NMCB.



## Chapter VI

### Conclusion

#### Conclusion

As stated earlier, the mission of the NCF is to support the United States Ground forces in wartime and contingencies situations. The many attributes associated with the slipform construction technique in the private sector are not vital in the carrying out of the NMCB mission. The economy and speed of the vertical slipform technique while attractive to the contractor and developer anxious to get the structure up and occupied as quickly as possible is less attractive to the NMCB Company Commander who does not have the trained personnel to insure the form's base and jacks are adequately installed. The jointless construction is very appealing to the owner of a seventy story high rise building but provides the BUC with little room for error in correcting an misalignment of structure which will never exceed twenty feet. There is no necessity for permanent road surfaces in contingencies situation making the need for concrete roads nonexistent. The quantity of concrete needed to keep a slipform paver efficiently active is beyond the capability of the mobile batch plants used in the limited concrete construction done by the NMCB. If the need arises for the construction of a



airfield in a contingency situation the NMCB is well versed in the installation of steel mated prefabricated sections which may be erected in a number of hours for the use of high performance aircraft. The use of civilian contractors in secured areas of conflict zones is also a medium for providing concrete construction capability which eliminates the need for the training and procurement of Naval personnel and equipment.

The slipform concrete construction technique is a method of construction which the Navy should continue procuring from the civilian sector when the need for a permanent structure is justified.



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